2025

AP® Physics C: Mechanics

Sample Student Responses and Scoring Commentary

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Free-Response Question 4

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Question 4: Qualitative Quantitative Translation (QQT) — 8 points

A	For indicating $f_D < f_R$	**Point A1**
	For a justification that compares **one** of the following: • The motions of the disk and the ring using translational kinematics • The motions of the disk and the ring using rotational kinematics • The rotational inertias of the disk and the ring	**Point A2**
	For a justification that includes **one** of the following: • Reasoning that attempts Newton's second law in translational form • Reasoning that attempts Newton's second law in rotational form • Reasoning that attempts conservation of energy	**Point A3**

Example Response

The ring has a greater rotational inertia because it has more mass distributed towards the edge. So the ring travels farther and has less acceleration down the ramp. Because the ring and the disk have the same mass, the gravitational forces exerted on the shapes are the same. From Newton's second law, the ring must have less net force down the ramp and more friction up the ramp.

B	For a multistep derivation that includes Newton's second law in both translational and rotational forms	**Point B1**
	For indicating opposite signs for the gravitational force and frictional force in an expression for Newton's second law	**Point B2**
	For using the relationship $a = r\alpha$ in an attempt to solve a system of equations **Scoring Note:** Responses that include conservation of energy may earn full credit.	**Point B3**

Example Response

$$\alpha_{sys} = \frac{\sum \tau}{I_{sys}}$$

$$\left(\frac{a}{R}\right) = \frac{fR}{I}$$

$$a = \frac{fR^2}{I}$$

$$\vec{a}_{sys} = \frac{\sum \vec{F}}{m_{sys}}$$

$$f - Mg\sin\theta = -Ma$$

$$f - Mg\sin\theta = -M\frac{fR^2}{I}$$

$$f + M\frac{fR^2}{I} = Mg\sin\theta$$

$$f\left(1 + \frac{MR^2}{I}\right) = Mg\sin\theta$$

$$f = \frac{Mg\sin\theta}{1 + \frac{MR^2}{I}}$$

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C	For indicating "Equal to"	**Point C1**
	For a justification that includes that kinetic friction is only dependent on the surfaces (or equivalently, the coefficient of kinetic friction between those surfaces) and normal force	**Point C2**
	Example Response *The forces of kinetic friction are equal. If slipping, the friction is kinetic, and the force of kinetic friction on the hoop and the disk are the same because the coefficient of kinetic friction is only dependent on the surfaces, and the normal forces on both are the same.*	

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Question 4

PART A

$f_D < f_R$

The ring travels further up the ramp, meaning that it takes a longer time to come to rest. That means that it has a smaller net translational acceleration, meaning that it has more friction to counteract gravity

PART B

$m = M$

$r = R$

$\tau = r \times F = fR = I\alpha$

$\alpha = \frac{fR}{I}$

$\alpha = \frac{a}{R}$

$a = \frac{fR^2}{I}$

$\Sigma F = ma = mg\sin\theta - f$

$ma + f = mg\sin\theta$

$m\frac{fR^2}{I} + f = mg\sin\theta$

$f\left(\frac{mR^2}{I} + 1\right) = mg\sin\theta$

$f = \frac{mg\sin\theta}{\left(\frac{mR^2}{I}\right) + 1}$

Question 4 is continued on the next page.

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Question 4

PART C

The frictional forces are the same. Since the materials of the disk and ring are the same, the coefficients of friction are the same. Since the masses of the ring and disk are the same and the ramp is the same, the normal force exerted by ramp is the same. Since $f_k = F_n \cdot \mu$, the frictional forces are the same

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Question 4

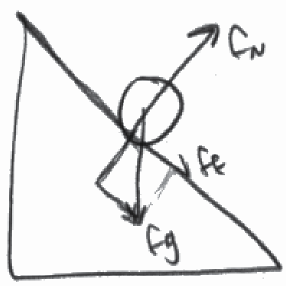
PART A

$f_f \le \mu_s f_N$

$f_f \le \mu_s mg$

$f_D > f_R$

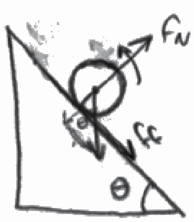
the inertia of the ring is greater, so the α of the ring is smaller $(\alpha = \frac{\tau}{I})$ so a is smaller $(a = \alpha r)$ so F_{net} is smaller $(F_{net} = ma)$ since $F_{net} = F_g \sin\theta + f_f$, f_f must be smaller for the ring.



PART B

$f_{f_s} \le \mu_s f_N$

$f_{f_s} \le \mu_s mg$



$a = r\alpha$

$\alpha = \frac{a}{r}$

$\alpha = \frac{f_f + g\sin\theta}{mR}$

$\frac{f_f \cdot R}{I} = \frac{f_f + g\sin\theta}{mR}$

$mR^2 f_f = I f_f + I g\sin\theta$

$f_f(mR^2 - I) = Ig\sin\theta$

$$f_f = \frac{Ig\sin\theta}{mR^2 - I}$$

$m\alpha = f_f + mg\sin\theta$

$ma = f_f + mg\sin\theta$

$a = \frac{f_f g + g\sin\theta}{m}$

$\alpha = \frac{\tau}{I}$

$\alpha = \frac{f_f \cdot R}{I}$

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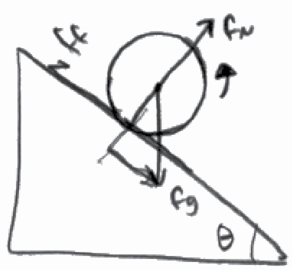
Question 4

PART C

Since the ring has a greater inertia, this means that the angular acceleration will be less than that of the disk. ($\alpha = \frac{\tau}{I}$) since the ~~α~~ is less then the acceleration (linear) is also less ($a = r\alpha$). Since the a is less the net force is also less ($F = ma$). Since the net force is less and since the mg is the same and the ff is now going upwards since its slipping, $fg_{\sin\theta} - ff$ is less so ff is greater for the ring.

$f_R > f_D$



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Q5523/19

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Question 4

PART A While the ring does travel further than the disk, that is due to the Inertia of the ring, not the friction force

$F_D = F_R$ because both are rolling without slipping and because both have the same mass and made of the same material, thus same static friction coefficient.

PART B Cylinder: $\frac{1}{2}MR^2 = I$

I is analogous to mass

$f_c = \mathcal{N} mg\cos\theta$

$F = ma$

$F = m\frac{dv}{dt}$

$v = r\omega$

$L = I\omega$

$L = \frac{1}{2}MR^2 \cdot \frac{v}{r}$

$P = F \cdot d$

$\mathcal{N} mg\cos\theta\, d = \frac{1}{2}MR^2 \cdot \frac{v}{r}$

$\mathcal{N} = \frac{\frac{1}{2}R \cdot v}{g\cos\theta\, d}$

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Question 4

PART C They have the same Kinetic frictional force.

Both are slipping so inertia doesn't play a role

$F_K = \mu_K mg \cos\theta$

B/c they have the same mass (m) and made of same material and thus same μ_K, they have the same F_K

Question 4

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

NEW for 2025: The question overviews can be found in the *Chief Reader Report on Student Responses* on AP Central.

Sample: 4A
Score: 8

Part A earned all three points. The first point (A1) was earned because the response correctly indicates that the frictional force on the disk is less than that on the ring. The second point (A2) was earned for comparing the motion of the two objects using translational kinematics, specifically by discussing their displacements. The third point (A3) was earned for providing a justification that attempts to apply Newton's second law through reasoning involving linear acceleration.

Part B earned all three points. The first point (B1) was earned for including a multistep derivation that incorporates both translational and rotational forms of Newton's second law. The second point (B2) was earned for correctly indicating that gravitational and frictional forces act in opposite directions within the Newton's second law expression. The third point (B3) was earned for attempting to solve a system of equations using substitution that connects linear and angular accelerations.

Part C earned both points. The first point (C1) was earned for correctly stating that the kinetic frictional forces on the ring and the disk are equal. The second point (C2) was earned for stating that kinetic friction depends only on the surfaces in contact and the normal force.

Sample: 4B
Score: 4

Part A earned two out of three points. The first point (A1) was not earned because the response does not state that the frictional force on the disk is less than that on the ring. The second point (A2) was earned for comparing the rotational inertias of the ring and the disk. The third point (A3) was earned because the justification includes reasoning using Newton's second law to compare linear accelerations.

Part B earned two out of three points. The first point (B1) was earned for presenting a multistep derivation involving Newton's second law in both its translational and rotational forms. The second point (B2) was not earned because the response does not clearly show that the gravitational and frictional forces act in opposite directions. The third point (B3) was earned for attempting to solve a system of equations by connecting linear and angular acceleration through substitution.

Part C did not earn either point. The first point (C1) was not earned because the response does not state that the kinetic frictional forces on the disk and ring are equal. The second point (C2) was not earned because the response does not state that kinetic friction depends only on the surfaces and the normal force.

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Question 4 (continued)

Sample: 4C
Score: 3

Part A earned one out of three points. The first point (A1) was not earned because the response does not indicate that the frictional force on the disk is less than that on the ring. The second point (A2) was earned for comparing the motion of the disk and ring using translational kinematics. The third point (A3) was not earned because the response lacks justification using Newton's second law or energy principles.

Part B did not earn any of the three points. The first point (B1) was not earned as the response does not contain a multistep derivation using Newton's second law in translational and rotational forms. The second point (B2) was not earned because there is no indication that gravitational and frictional forces act in opposite directions. The third point (B3) was not earned because the response does not attempt to solve a system of equations using substitution or by linking linear and angular accelerations.

Part C earned both points. The first point (C1) was earned because the response correctly indicates that the kinetic frictional forces on the disk and ring are equal. The second point (C2) was earned for stating that kinetic friction depends solely on the nature of the surfaces and the normal force.

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